Numerical Modeling of Seabed Gouging by Ice Masses

and soil-pipe interaction

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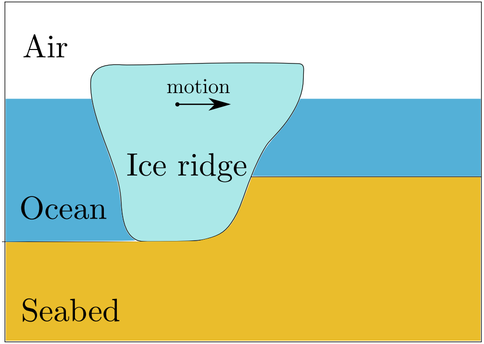
Outline

Arctic Ocean

(*Courtesy of Polar Science Center at Washington University*)

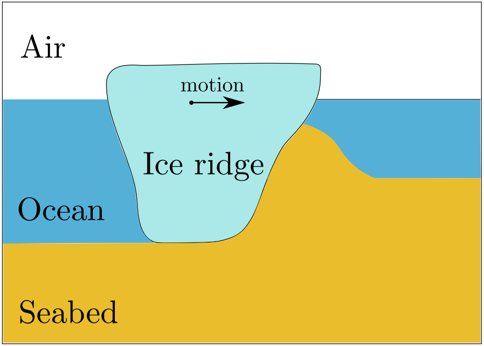
- Home to large untapped reserves
  - 13% oil reserves [1]
  - 30% gas reserves [1]
- Marine pipelines for transportation of fluids
  - Install on seabed
  - Trench and/or embed into seabed
    - Less susceptible to man-made hazards
    - Susceptible to seabed gouging by ice masses

Seabed scour



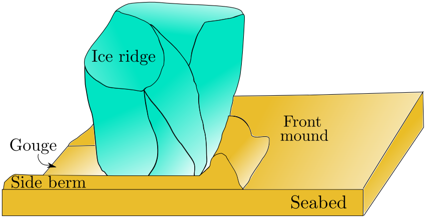
- Ice features drifting in Arctic environment.
- Come in contact with seabed in shallower waters.
- Scour the seabed for several kilometers.

Seabed scour

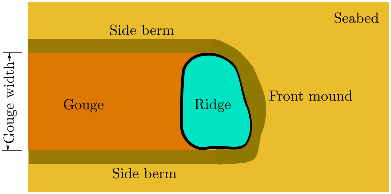


- Scour seabed and remold the seabed surface.
- Limited information available about actual process.
- Move at speeds of 0.1 m/s.
- Scour deformation occurs in undrained condition.

Seabed scour



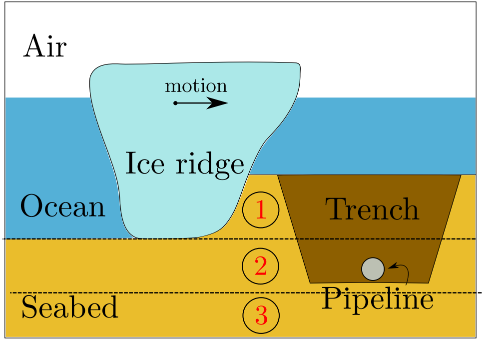
(a) Isometric View



(b) Top View

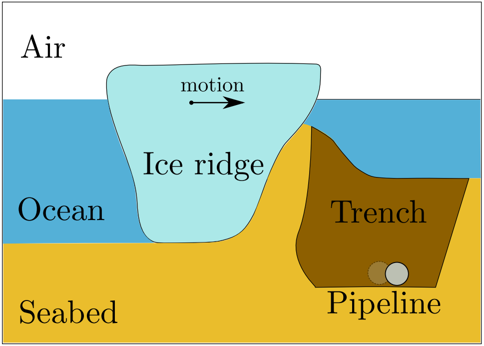
- Gouge depths typically rarely exceeding 1m in depth.
  - Canadian Beaufort Sea (1970s): 2.5m [4]
  - Canadian Beaufort Sea (1995): 0.3m [2]
  - Grand Banks (2004): 0.3m [3]
- Inherently a 3-dimensional problem.

Seabed Scour and Pipe Interaction



- Trench and embed pipelines to prevent contact with ice ridges.
- Fill trench back with infill.
- Deeper trenches more expensive.

Seabed Scour and Pipe Interaction



- Indirect transfer of forces to pipeline
- Concern about the safety of pipes.
- Study behavior of pipes under extreme loading due to ridges.

Classical Approach: Soil-Structure Interaction (SSI)

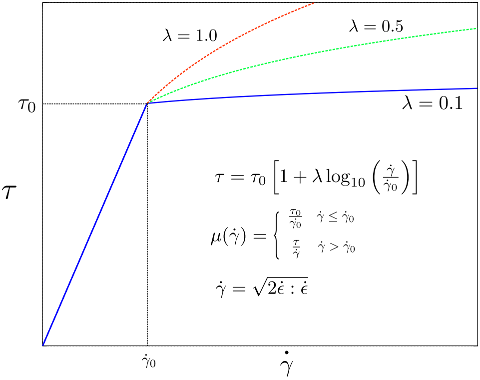
Seabed scour modeling:

- Soil modeled as a porous medium.
  - Accurate model for soil.
  - Includes load-history dependency behavior of soil.
- Large deformations require re-meshing.
  - Computationally expensive.
  - Solution projection between meshes deteriorates nonlinear convergence.
  - Difficult to parallelize.
- Requires solving a nonlinear contact problem.

Current Approach: Fluid-Structure-Object Interaction

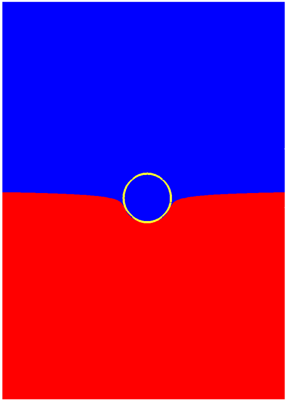
- Model soil as a highly viscous non-Newtonian fluid with a “yield” stress.
  - Herschel-Bulkley model used to approximate soil behavior.

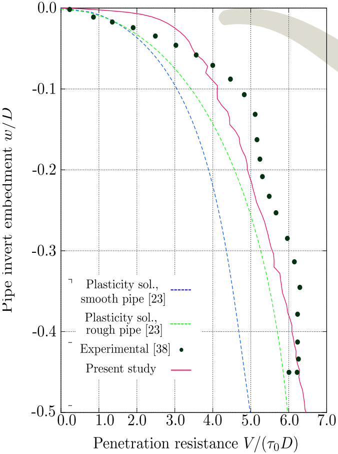
$$\boldsymbol{\sigma}^f = 2\mu^f(\dot{\gamma})\,\dot{\boldsymbol{\epsilon}} - p\mathbf{I}, \quad (1)$$



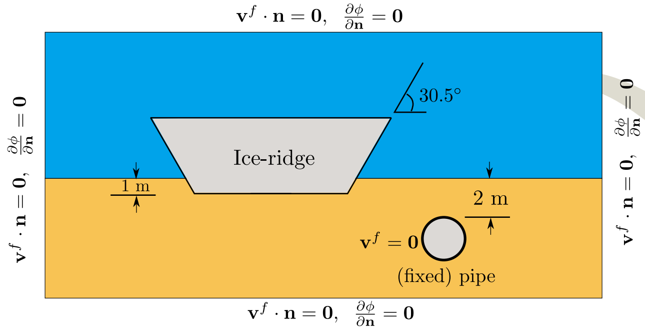
Pipe Penetration

Rigid cylinder, w/ streamlines   Rigid cylinder, w.o streamlines





Ridge Scour

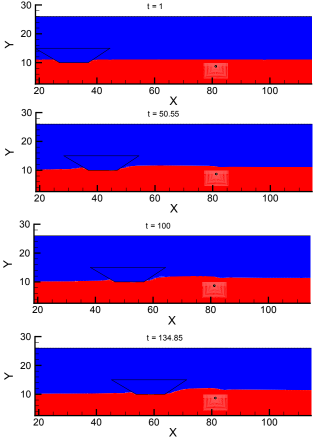


Case I

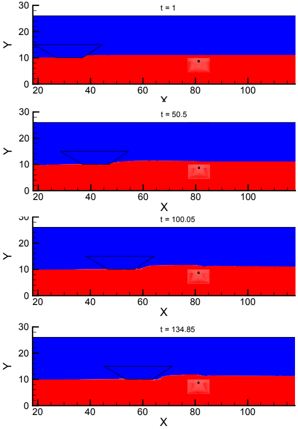
Case II

Ridge Scour

Case I

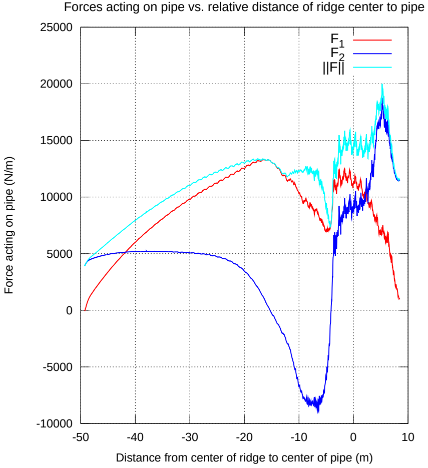


Case II



Seabed scour

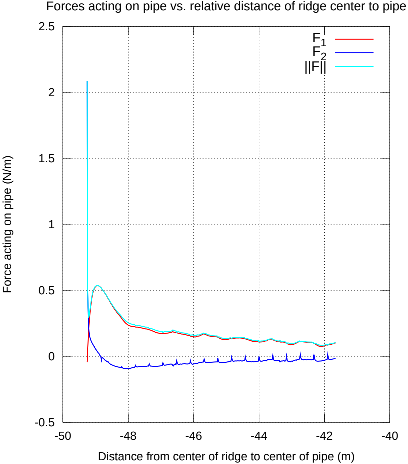
fixed pipe

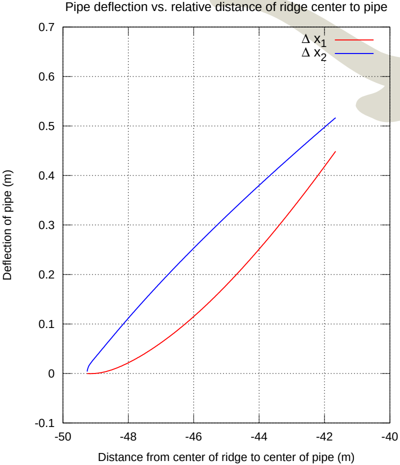


- Extreme cases:
  - Pipe artificially fixed in place.
  - Pipe artificially allowed to freely “float”.
- Pipe allowed to displace, attached to spring.

Seabed scour – "floating" pipe

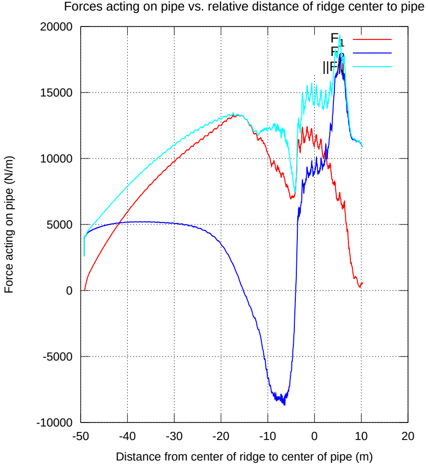
▸ floating pipe

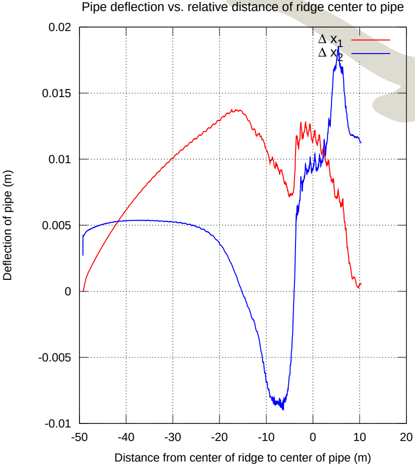




Seabed scour – Pipe with artificial spring

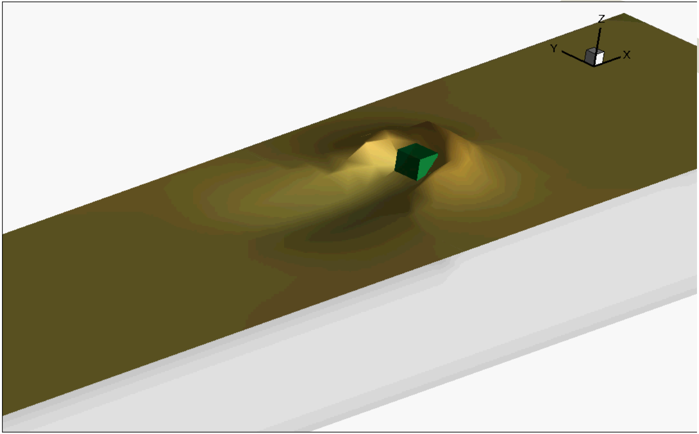
Pipe with spring





3-dimensional Scour (without pipe)

3d Scour



Concluding Comments

- Approximating soil behavior using Herschel-Bulkley model promising.
- Problem is very computationally demanding.
  - $\sim$ 36 hr for a typical 2D run on a single core.
  - Projected run time of 5-10 days for 3D analysis on TACC (16 cores).
- Currently working on parametric studies.

Sources I

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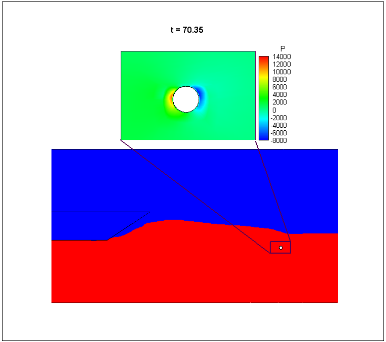
Application: Ridge scour

Table 1: Properties used for preliminary runs of ridge scour

Scour depth	1 m.
Ridge base width	10 m.
Ridge speed	0.2 m/s.
Attack angle	30.5 deg.
pipe diameter	24 in.
Yield stress	1765 Pa.
Yield strain-rate	0.024 1/s
soil mass density:	1400 kg/m3
water mass density:	1000 kg/m3
water dyn. viscosity:	1e-3 kg/m.s

Ridge scour: Case I with no gravity

No gravity



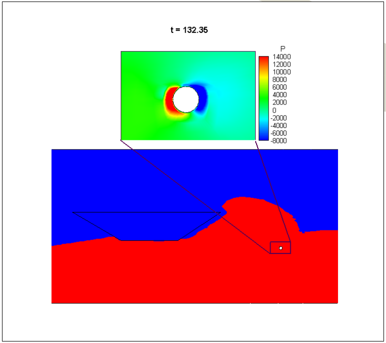


Figure 1: Case I – Seabed perturbation (gravity off)